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TITLE: CAVITY SHAPE AND BEAM DYNAMICS DESIGN FOR A LINAC FOR PIONS

**AUTHOR(S): GEORGE R. SWAIN
LOS ALAMOS NATIONAL LABORATORY**

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Cavity Shape and Beam Dynamics Design for a Linac for Pions*

G. Swain

Los Alamos National Laboratory
P. O. Box 1663, MS H847
Los Alamos, NM 87545

Abstract

A linac to accelerate pions from 400 to 920 MeV kinetic energy is being designed as an enhancement to the LAMPF accelerator facility at Los Alamos. Calculations for the design of the superconducting cavity shape attempt to reduce the peak surface field needed to achieve a given accelerating gradient, yet maintain sufficient cell-to-cell coupling to maintain field stability when microphonics or other tuning errors are present. The beam dynamics design has the goal of getting the highest possible flux of pions in a narrow momentum range at the end of the linac. In order to do this, the design takes into account the survival fraction from pion decay, and optimizes the acceptance of the combination of the transport line from the pion production target to the entrance of the linac and the linac itself.

I. INTRODUCTION

A proposed linear accelerator for pions ("Pilac") would extend the capabilities of the Los Alamos Meson Physics Facility (LAMPF). Pilac is to accelerate pions from a new target on the 800 MeV proton beam line A. The pions are to be accelerated from around 380 MeV to kinetic energies up to 1120 MeV, corresponding to a momentum of 1250 MeV/c. This project has the goal of providing a flux of 10^9 pions per second at 920 MeV (1050 MeV/c momentum). The linac is to use superconducting rf cavities in order to provide large apertures and transverse acceptance, and produce high accelerating gradients without a large cost in rf power. We have chosen 805 MHz as the operating frequency in order to get the acceptance we need with cavities of practical size.

CAVITY SHAPE

Our initial studies of cavity shapes for 805 MHz considered cavities which had circular arcs for the cavity profile, both at the cavity waist and at the noses where cells join. We did a series of calculations with various cell apertures and various nose radii. The line segments between waist and nose arcs were at 10 deg from the vertical for all cases. The ratios of peak surface field E_{max} to accelerating gradient E_0T for these shapes are summarized in Figure 1.

Subsequently, we have looked at cavities with elliptical noses. Five cases with beam apertures of 13 cm diameter are

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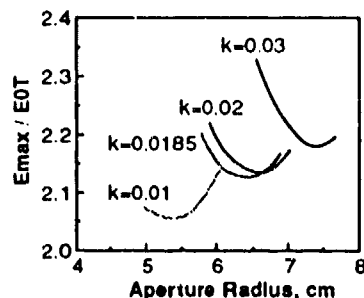


Figure 1. Peak surface field per accelerating gradient for cavities with circular noses for several values of cell-to-cell coupling k .

listed in Table I. All of these used ellipses with 2.1 ratio of major to minor axes.

Table I
Coupling and Peak Surface Electric and Magnetic Field
vs Elliptical Nose Major Axis Length

| Nose MA (cm) | Coupling (%) | E_{max}/E_0T | H_{max}/E_0T (A/V) |
|-----------------|-----------------|----------------|-------------------------|
| 23. | 1.604 | 1.831 | 4673.9 |
| 18. | 2.037 | 1.862 | 4157.7 |
| 16. | 2.247 | 1.920 | 3988.4 |
| 13. | 2.619 | 2.030 | 3772.2 |
| 11. | 2.916 | 2.164 | 3652.1 |

For the cavities with circular noses, the minimum E_{max}/E_0T for 6.5 cm radius aperture was about 2.13, and for this, the nose radius was 3.5 cm and the coupling k was 1.85%. With an elliptical nose, we have less mechanical stress, and for a major axis of 13 cm, E_{max}/E_0T is better at 2.03, and the coupling stronger at 2.6%. This is the configuration that we have chosen for Pilac. See Figure 2.

LINAC DESIGN

In order to evaluate alternative linac designs, we have used a figure of merit which is the product of two factors: (a) beam acceptance and (b) survival fraction. The survival fraction is the fraction of pions entering the linac that have not been lost to decay by the time they reach the linac exit. We are using the term acceptance in a specialized sense. Normally, one takes it to mean the area in energy-phase space at the start of the linac such that the particles are accelerated, such as the larger dotted area in Figure 3. For our purpose, we take acceptance to mean the area in energy phase space for which

the pions are within 1.5% full width momentum spread (dp/p) around the desired energy at the exit of the linac, a much smaller area. Moreover, we use the energy-phase space at the pion production target, not at the linac entrance.

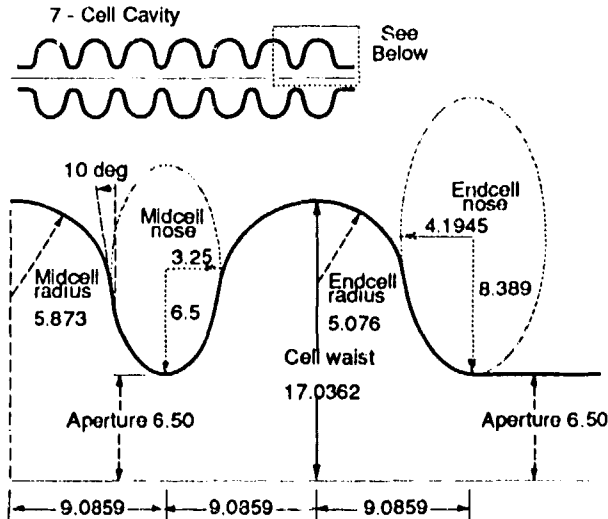


Figure 2. Pion cavity geometry.

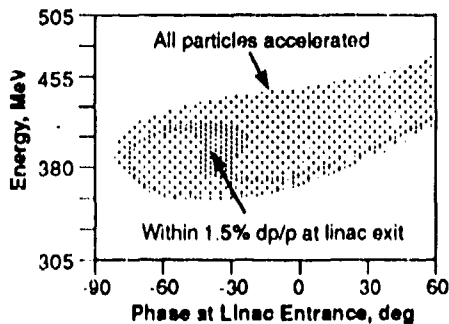


Figure 3. Acceptance areas.

We wish to capture a beam pulse at the pion production target that is 80 ps long. The beam bunch at the production target is skewed by the injection line in energy-phase space, and then rotated by the linac. In order to maximize the acceptance, we choose the rf phases of the cavities such that the beam bunch comes out narrow in energy width at the linac exit. We assume that the longitudinal effect of the beam line from the pion production target to the entrance to the linac is approximately equivalent to a drift, and the equivalent drift length for 380 MeV is 11 m.

Transverse Considerations

We used 7-cell 805-MHz cavities and quadrupole doublets (36 cm effective length quads spaced 36 cm apart) in our reference design. For transverse beam acceptances of 225π mm-mrad, and allowing space for valves, bellows, etc., this led to the configuration shown in Figure 4.

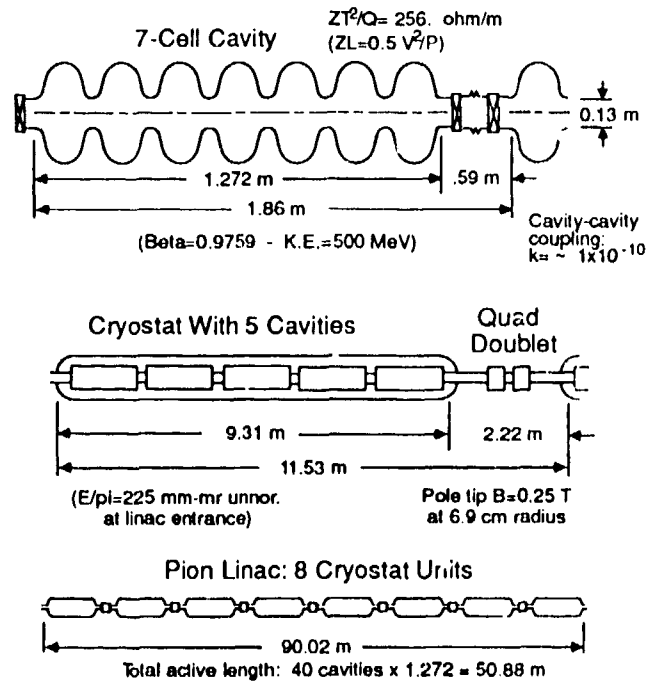


Figure 4. Reference linac configuration.

Longitudinal Acceptance Optimization

We chose the rf phases of the cavities in the linac such as to optimize the beam acceptance. We used the computer program LINO3 to do this. LINO3 divides a 40-cavity linac into eight sections, and adjusts the phases of the sections, and not each individual cavity phase. The optimization is done in two stages, as shown in Figure 5.

The rf phases found by the optimizer for the reference linac are given in Table II.

Table II
Design RF Phases

| Section No. | Range of Cavs. | Design Phase for Section, deg |
|-------------|----------------|-------------------------------|
| 1 | 1, 3 | -68.06 |
| 2 | 4, 6 | -2.049 |
| 3 | 7, 9 | -18.23 |
| 4 | 10, 12 | -24.85 |
| 5 | 13, 18 | -52.55 |
| 6 | 19, 24 | -4.904 |
| 7 | 25, 30 | -8.891 |
| 8 | 31, 40 | -9.913 |

Reference Case Performance

The acceptance achieved is 82 ns wide (24 deg) by 6% FW dp/p . Figure 6 shows the result of tracing a 80 ns by 6% dp/p beam through the linac. The concave distortion introduced in the first part of the linac is largely taken out later when the bunch is rotated with the other side up [1].

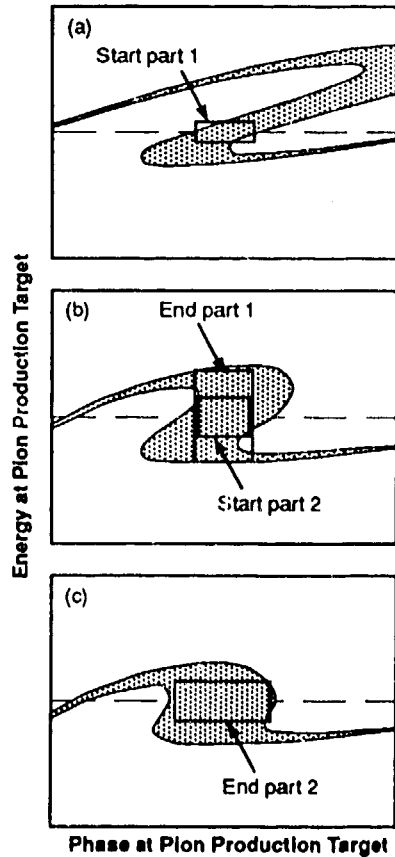


Figure 5. Part 1 of the acceptance optimization begins with uniform rf phases and expands a rectangular acceptance area in energy, (a) to (b). Part 2 expands the area in phase, (b) to (c). Each plot above is 72 deg wide by 100 MeV tall, with the 380 MeV design starting energy at the dotted line.

The variation of the transverse beam size through the linac is shown in Figure 7, and stays below the 6.5 cm aperture radius.

OTHER CASES

We have found that for acceleration from 380 to 606 MeV, we obtain 62% of the beam flux obtained at 920 MeV; and that for 380 to 821 MeV, we obtain 80%. Further studies for other exit energies are in progress.

CONCLUSIONS

A cavity shape with a surface to accelerating field ratio of 2.03 and a cell-to-cell coupling of 2.65% has been selected. An acceptance optimization procedure has led to a reference design for a 380 to 920 MeV linac. The linac uses 40 seven-cell 805-MHz cavities, and will accept a beam with 225π mm-mrad unnormalized emittance in both transverse planes, and with a 80 ps time width and 6% full width dp/p in the

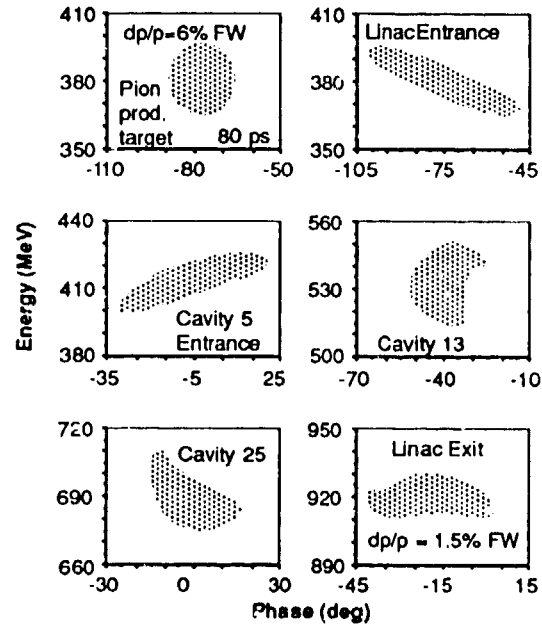


Fig. 6. Longitudinal evolution of the bunch.

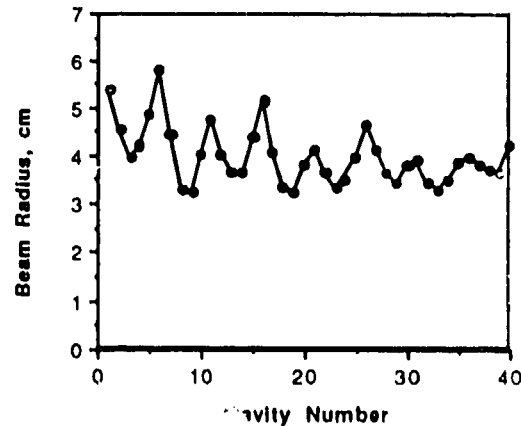


Figure 7. Maximum transverse beam size.

longitudinal plane. To realize this acceptance, the injection beam line should be capable of transporting a beam with 6.6% full width dp/p .

A quadrupole doublet is used after every 5th cavity. Of the pions entering the linac, 11.6% survive at the exit for a peak accelerating gradient $EOT = 12.46$ MeV/m.

XIV. REFERENCES

- [1] S. Nath, G. Swain, R. Garnett, and T. P. Wangler, "Beam Dynamics Design of a Pion Linac," Proceedings of the 1990 Linear Accelerator Conference (Los Alamos Nat. Lab. report LA-12004-C), Albuquerque, NM, September 10-14, 1990, pp. 338-340.